GEOTECHNICAL METHODS FOR DETERMINING THE
EROSIONAL CHARACTERISTICS OF DREDGE SPOILS

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A REPORT TO
DEPARTMENT OF THE ARMY
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SYNOPSIS

This report is concerned with the use of a rotating concentric cylinder viscometer to determine the rheological properties of redeposited dredge materials.

The materials studied were from the Taunton River, Fall River, Massachusetts and the Thames River, New London, Conn. and were supplied by the New England Division Corps of Engineers.

The tests were performed using a Brookfield viscometer with a U.L. adapter. Samples were prepared with varying concentrations and salinities of 30 percent and 50 percent. Relationships between viscosity and concentration as well as Bingham shear stress and concentration for the spoil material were determined. Also, a relationship between critical erosional velocity and Bingham shear, with the limited amount of data available, was determined.

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INTRODUCTION

The New England Corps of Engineers is charged with the maintenance of harbors and waterways along the northeastern Atlantic Coast. This work includes dredging in areas such as the Taunton River, Fall River, Mass. and the Thames River in New London, Conn., in which these spoils are composed of organic silts. Possible disposal sites include Continental Shelf Areas. Therefore, the New England Division is interested in obtaining information on the erosional behavior of redeposited spoils. It is toward this goal that this research is directed.

The particular objective of this research is to investigate those geotechnical methods that might be used to gain insight into the erosional behavior of redeposited spoils. A rotating concentric cylinder viscometer was used to determine the viscosity and Bingham shear stress for spoil material with a salinity of 30 percent and various concentration or water contents.

The material studied was supplied by the New England Division Corps of Engineers under Contracts DACW 33-74-M-0746 and DACW-33-75-M-0956 and was reportedly removed from the Taunton River, Fall River, Mass. and the Thames River, New London, Conn. The soil parameters for the materials are given in Nacci, et al (1974) and Nacci, et al (1975).

DESCRIPTION OF APPARATUS AND EXPERIMENTAL PROCEDURE

The samples were tested with a Brookfield Model LVF viscometer using a U.L. adapter. The unit is essentially a motor driven torque meter, measuring the torque mobilized by the sediment in the U.L. adapter. Torques up to 673 Dyne-cm can be measured on a scale of 0 to 100. The U.L. adapter

consists of an outer cylinder (2.762 centimeter diameter) into which the sample is placed. Into the outer cylinder, in addition to the sample, an inner cylinder or "bob" is placed which has a diameter of 2.515 centimeters. A sample volume of 30 cubic centimeters is used. In the configuration described above a range of viscosities from 0 to 100 centipoise is possible with RPM's ranging from 6 to 60. The higher viscosities reported were obtained using a Brookfield Rheolog HAT viscometer which can measure torques up to 14,374 Dyne-cm. In all of the tests reported herein the spoil material was passed wet through a #40 sieve prior to testing. Additional amounts of salt (NaCl) and fresh water were then added to the samples to obtain the desired concentrations and salinities.

DISCUSSION OF THE DETERMINATION OF VISCOSITY
AND BINGHAM SHEAR STRENGTH

As stated above, the dredge material was placed between the concentric cylinders. The inner cylinder was rotated and the torque required to maintain a constant RPM was recorded.

The flow between the rotating cylinders is described by the following equations:

(Navier-Stokes)

$$\rho \frac{u^2}{r} = \frac{dP}{dr}$$

(1)

(Which describes the radia pressure distribution due to rotation)

and
$$\frac{d^2u}{dr^2} + \frac{d}{dr}\left(\frac{u}{r}\right) = 0$$

(2)

where, u, is the circumferential velocity, and the boundary conditions are

$$u = r_1 \omega_1 \quad \text{for} \quad r = r_1$$

$$u = -r_2 \omega_2 \quad \text{for} \quad r = r_2 \tag{3}$$

The solution for the circumferential velocity as a function of radius is given by Schlichting (1968) as:

$$u(r) = \frac{1}{r_2^2 - r_1^2} \left[r \left(\omega_2 r_2^2 - \omega_1 r_1^2 \right) - \frac{r_1^2 r_2^2}{r} \left(\omega_2 - \omega_1 \right) \right] \tag{4}$$

Now, if the spoil material is modeled as a Bingham plastic the shear stress mobilized on the wall of the cylinders is given by:

$$T = T_b + \mu \left(\frac{du}{dr} - \frac{u}{r} \right) \tag{5}$$

where T_b is the Bingham yield stress and, μ, is the viscosity. The torque in the annulus is given by:

$$T = 2\pi r^2 h \left[T_b + \mu \left(\frac{du}{dr} - \frac{u}{r} \right) \right] \tag{6}$$

Note if expression (4) is differentiated and substituted into expression (5) and integrated with the appropriate boundary conditions, the following is obtained:

$$T = \mu \, 4\pi h \, \frac{r_1^2 r_2^2}{r_2^2 - r_1^2} \, \omega + 4\pi h \, \frac{r_1^2 r_2^2}{r_2^2 - r_1^2} \ln \frac{r_2}{r_1} \, T_b \tag{7}$$

where, T, is the torque measured on the inner cylinder (dyne-centimeters); μ, is the viscosity in poise; h, is the theoretical height of the cylinder, that is includes the

shear that occurs on the top and bottom of the cylinders (centimeters); r_1, is the radius of the inner cylinder (centimeters); r_2, is the inside radius of the outer cylinder (centimeters); ω, is the rate of rotation of the inner cylinder (radius/second); ln, is the natural logarithm; and $\mathcal{T}_b$, is the Bingham shear stress.

For the concentric cylinder apparatus used, expression (7) reduces to:

$$T = \mu \; 112.48 \;\; N + 100.61 \; \mathcal{T}_b$$

(8)

where additionally, N, is the rotation of the inner cylinder in reductions per minute.

On each sample a series of tests were performed in which the torque required for each RPM was recorded.

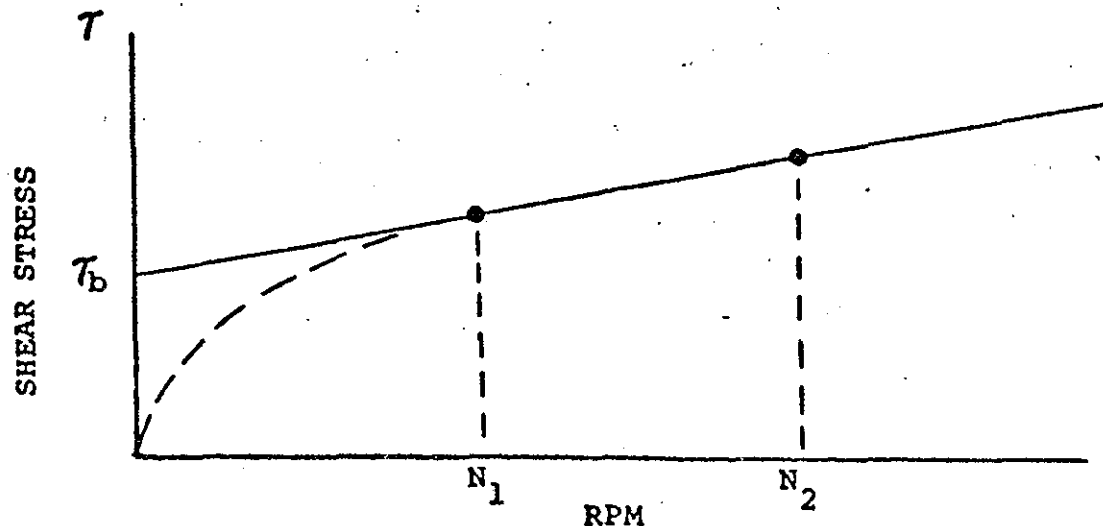Next the assumption of a Bingham model is made. This is illustrated in Figure 1.

FIG. 1. BINGHAM MODEL

For the Bingham approximation two RPM's are selected, N_1 and N_2 and expression (8) is treated as two simultaneous equations, eliminating τ_b. This allows the determination of the viscosity,μ, for the model or the slope of the straight line in Figure 1. The viscosity is then used in expression (8) and the Bingham shear stress (intercept of the straight line with the shear stress axis) is determined. These results are given in Table 1.
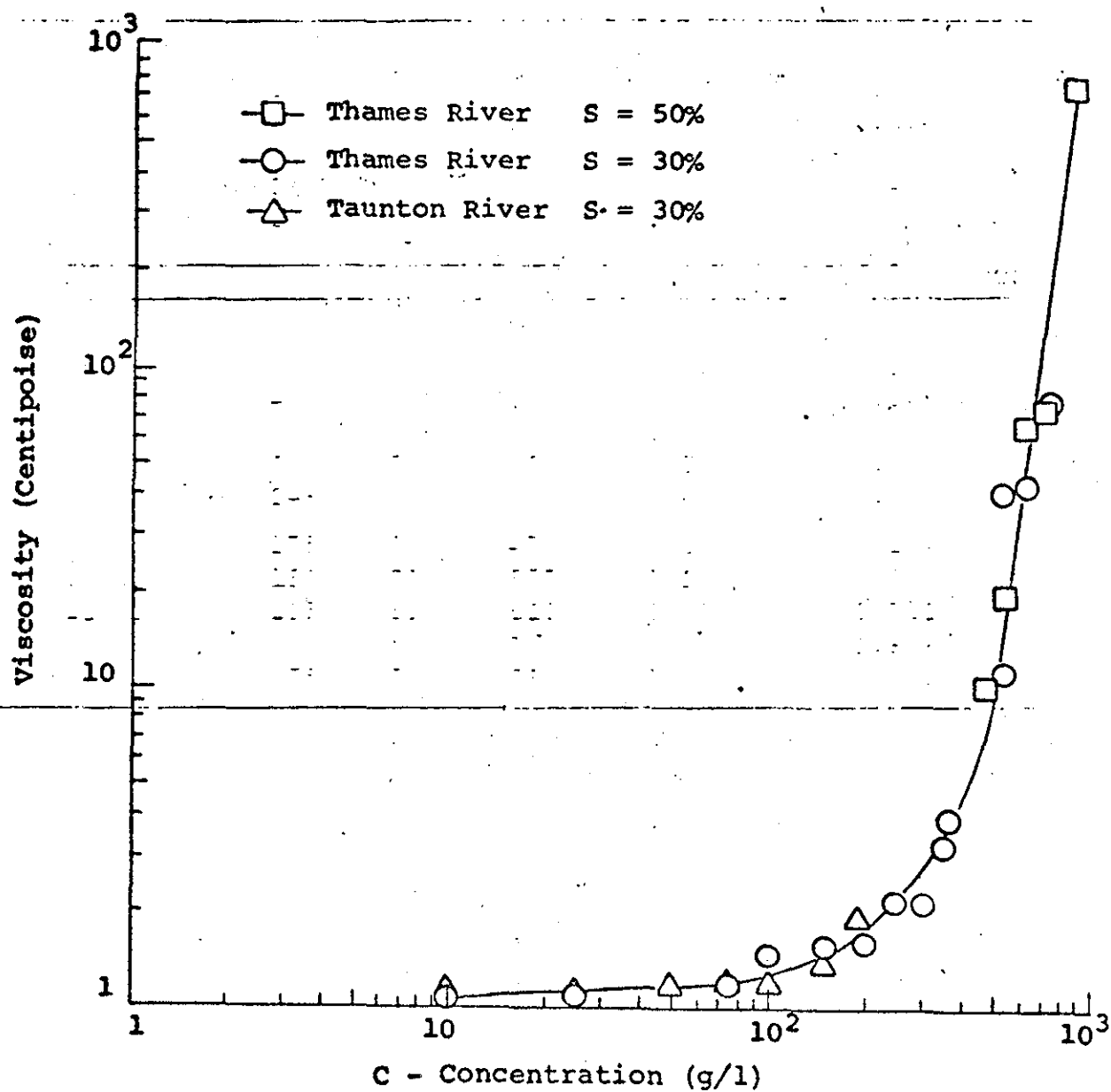
The tabulated results are plotted in Figures 2 and 3. The expression used in this report relating concentration to water content is plotted in Figure 4. This concentration is grains of dry solids per combined volume of solids and water.

RESULTS AND CONCLUSIONS

From Figure 3 it can be seen that the Bingham shear stress increases with increasing concentration or decreasing water content. The relationship appears to be similar for both the Taunton and Thames River spoils with a salinity of 30 percent, but for the Thames River spoils with a salinity of 50 percent a different and more sensitive relationship exists between Bingham shear stress and the concentration of solids.

Next, a relationship between critical erosional stress and Bingham shear stress will be illustrated, but since only two critical shear stress are available, determined under previous contracts with the Corps, caution should be excercised in using these values.

The critical erosional velocities, obtained under previous grants from the Corps, were 2.14 Dynes/cm^2 and 3.14 Dynes/cm^2 for the Taunton and Thames River spoils, respectively.
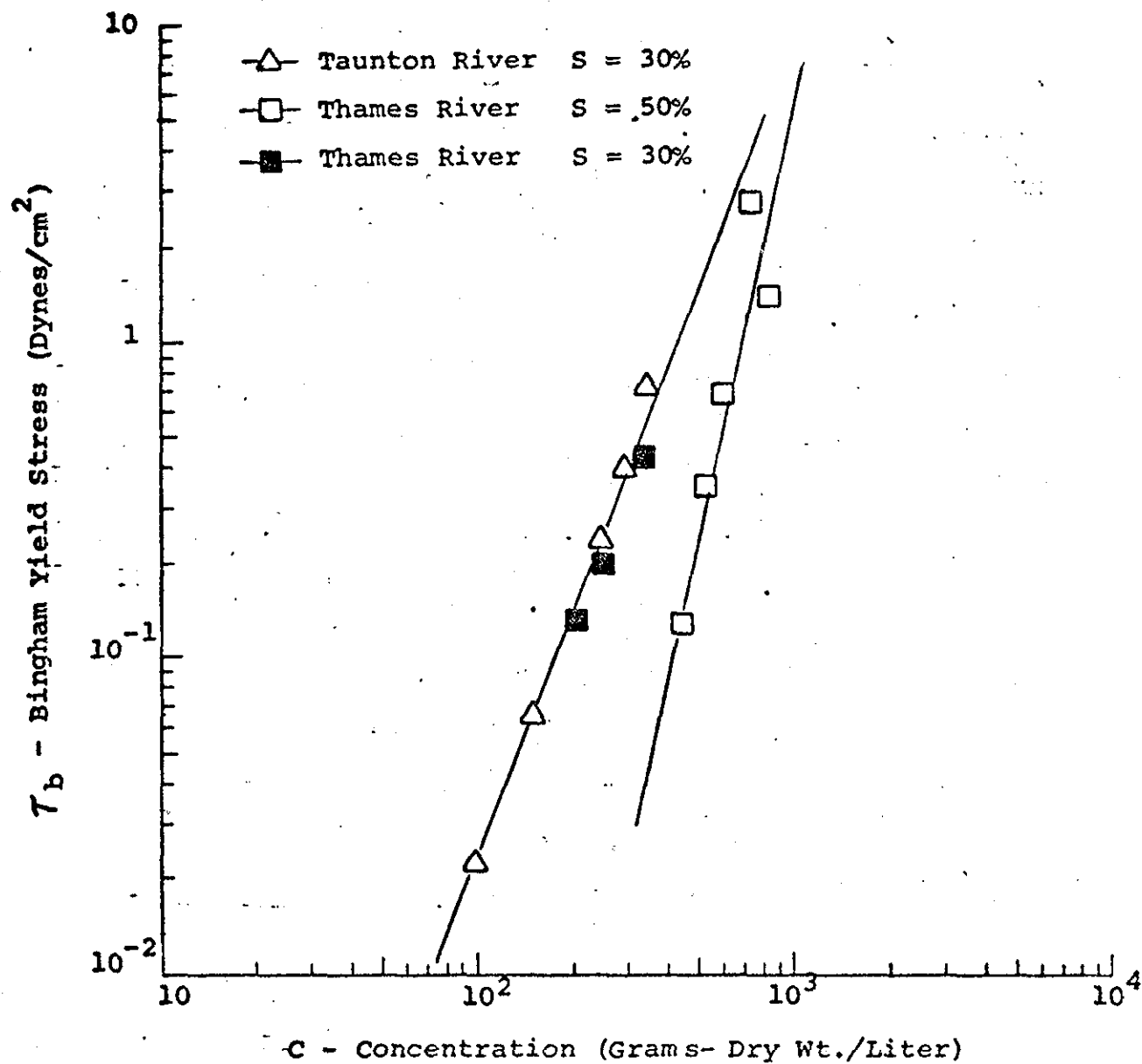
TABLE 1.   Viscometer Test Data

Sample	%	%	C g/l	CPS	T_b Dynes/cm^2
TAUNTON RIVER SAMPLES					
FR MC 963 S30	963	30	100	1.13	0.0226
FR MC 630 S30	630	30	150	1.30	0.0596
FR MC 463 S30	463	30	200	1.29	0.1345
FR MC 363 S30	363	30	250	2.56	0.239
FR MC 296 S30	296	30	300	3.22	0.403
FR MC 249 S30	249	30	350	3.69	0.7624
THAMES RIVER SAMPLES					
TR MC 963 S30	963	30	100	1.26	0.0709
TR MC 630 S30	630	30	150	1.42	0.0509
TR MC 463 S30	463	30	200	1.69	0.140
TR MC 363 S30	363	30	250	1.29	0.1345
TR MC 296 S30	296	30	300	1.82	0.1035
TR MC 249 S30	249	30	350	3.4	0.0396
TR MC 175 S50	175	50	470	0.103	0.134
TR MC 150 S50	150	50	535	0.205	0.361
TR MC 125 S50	125	50	620	0.693	0.7126
TR MC 100 S50	100	50	725	0.77	2.85
TR MC 75 S50	75	50	890	7.7	1.421

both the Taunton and T ... ...

30 percent, ...

of 5 percent ...

... ...

of solids.

...

and ... ...

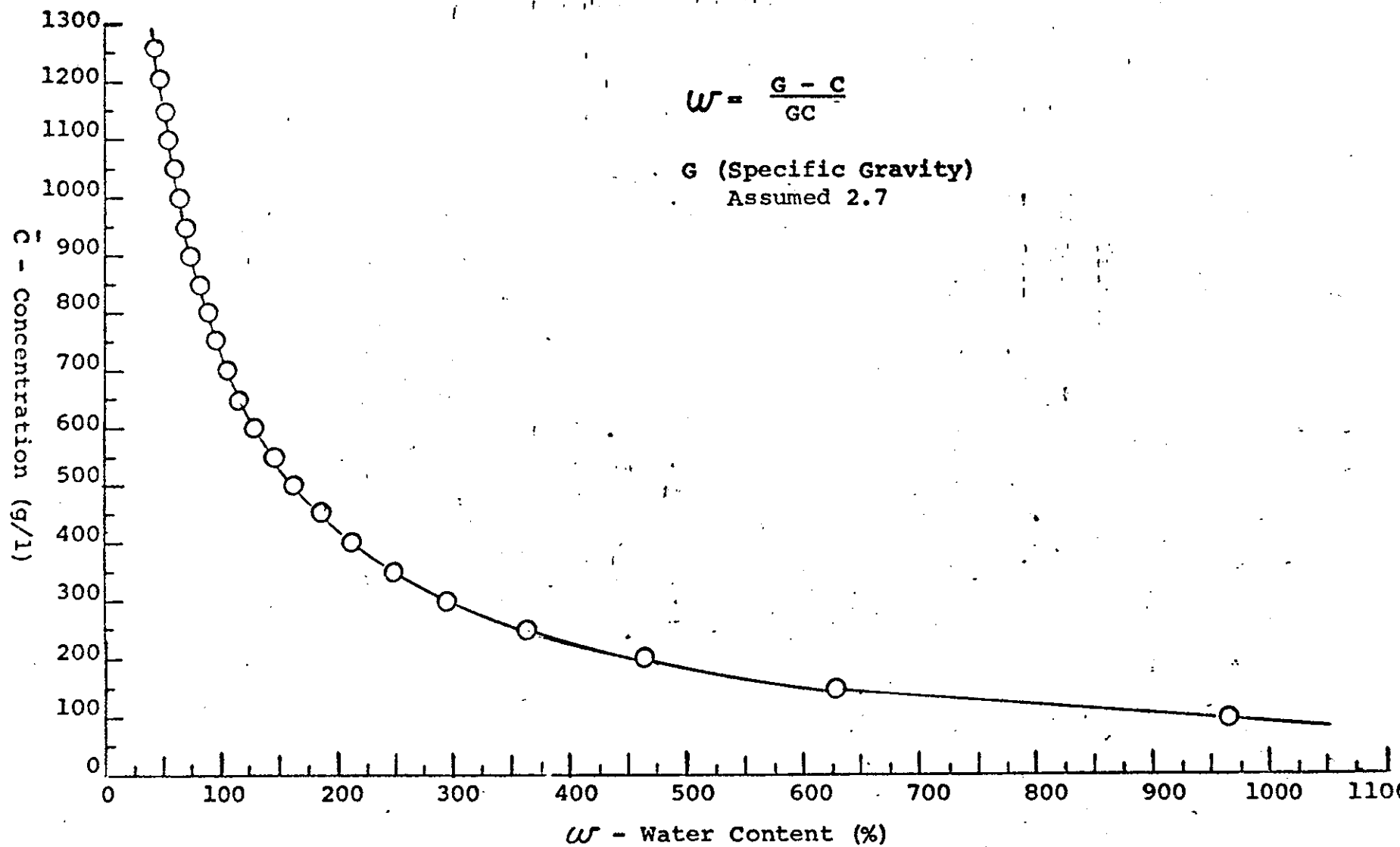FIGURE 2. VISCOSITY VERSUS CONCENTRATION
FOR SPOIL MATERIAL

FIGURE 3.   BINGHAM YIELD STRESS VERSUS CONCENTRATION
            FOR SPOIL MATERIAL

FIGURE 4. CONCENTRATION-WATER CONTENT RELATIONSHIP

$$w = \frac{G - C}{GC}$$

G (Specific Gravity) Assumed 2.7

C – Concentration (g/1)

w – Water Content (%)

A review of the data indicates that the natural water content
of the Taunton River spoils was of the order of 140% or a
concentration of 555 g/l; similarly, for the Thames River
spoils a water content of 650 g/l was indicated. Using
Figure 3, a Bingham shear stress of 2 Dynes/cm^2 is obtained
for the Taunton River and 3 Dynes/cm^2 for the Thames River
spoils. Using this data a relationship between critical
erosional shear stress, T_c , and Bingham shear stress, T_b ,
was found to be: $T_c = 1.11 \ T_b^{0.9455}$ or that the critical
erosional shear stresses for the Taunton and Thames River
spoils are roughly the same order of magnitude as the Bingham
shear stress. This should be contrasted with the relationship
given by Migniot (1968), i.e., for $T_b < 10$ Dyne/cm^2; $T_c = \rho \ T_b^{\frac{1}{2}}$.
The reasons for the difference are fourfold: First, the methods
of testing used by Migniot required sedimenting the viscometer
bob in the sediment, as opposed to the method proposed herein;
second, the definition of concentration used by Migniot is
unknown at this time; third, not enough data on critical shear
stress for the spoils used are available at this time; and finally,
the high organic content of the spoils may be significant.

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